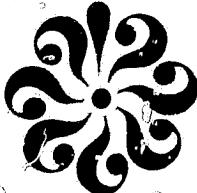


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DEPARTMENT OF PHYSICS  
SCHOOL OF SCIENCES AND HEALTH PROFESSIONS  
OLD DOMINION UNIVERSITY  
NORFOLK, VIRGINIA

Technical Report PTR-81-4

PROPAGATION OF SOUND THROUGH THE EARTH'S  
ATMOSPHERE:

- I. MEASUREMENT OF SOUND ABSORPTION IN THE AIR AND
- II. MEASUREMENT OF GROUND IMPEDANCE

By

Jacob Becher

and

Roger W. Meredith

Principal Investigator: Allan J. Zuckerwar  
(from January 1 to September 28, 1980)

Final Report

For the period July 1, 1980 - June 30, 1981

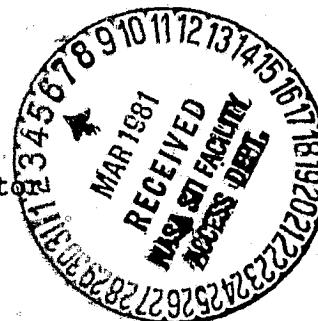
Prepared for the

National Aeronautics and Space Administration  
Langley Research Center  
Hampton, Virginia

Under

Research Grant NAG-1-15

Harlan K. Holmes, Technical Monitor  
Instrument Research Division



January 1981

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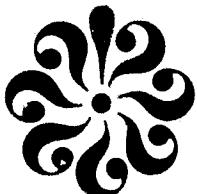
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P.O. Box 6369  
Norfolk, Virginia 23508



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- I. MEASUREMENT OF SOUND ABSORPTION IN AIR AND
- II. MEASUREMENT OF GROUND IMPEDANCE

By

Jacob Becher<sup>1</sup> and Roger W. Meredith<sup>2</sup>

SUMMARY

This report summarizes work accomplished under NASA grant NAG1-15 since July 1, 1980. This work is described under four major subject headings: (1) acoustic ground impedance meter, (2) automatic data-processing system, (3) cooling system for the resonant tube, and (4) final results of sound absorption in  $N_2-H_2O$  gas mixtures at elevated temperatures.

ACOUSTIC GROUND IMPEDANCE METER

The fabrication of parts for the acoustic ground impedance meter has been completed, and the instrument has been tested. The volume velocity source, using the five-lobed cam and the LED-photodiode monitor, functioned as expected. However, mechanical vibrations from the volume velocity source produced chatter to such an extent as to overwhelm the microphone signal. This problem was eliminated by unscrewing the resonator neck from the chamber and reconnecting the two parts by means of a rubber hose to suppress vibration. The neck is currently being modified for mounting on the center post of a camera tripod. It can then be lowered to a favorable height above the chamber and connected with the rubber hose.

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## AUTOMATIC DATA-PROCESSING SYSTEM

The Datel Intersil A/D converter model ADC-HC12B has been successfully integrated into the Apple II Computer detection system. Software for controlling the A/D conversion rate and data storage is currently being developed and tested. Software for graphics and evaluation of the free decay curves has been initiated.

## COOLING SYSTEM FOR THE RESONANT TUBE

When the initial cooling system proved ineffective in cooling the resonant tube to 0° C (32° F), the cooling system piping was insulated. Even with the added insulation, the cooling system was ineffective. The cooling system was modified to use liquid nitrogen coolant by passing liquid nitrogen from a nearby trailer. The liquid proved to be sufficient to cool the resonant tube to the required temperature; however, the temperature gradient within each of the four tube sections reached unacceptable levels. Figure 1 shows the results of the cooling test and the resulting temperature gradient for one tube section. Modifications to the cooling system are presently being designed and implemented so that each tube section can be cooled more uniformly.

## FINAL RESULTS OF SOUND ABSORPTION IN N<sub>2</sub>-H<sub>2</sub>O GAS MIXTURES AT ELEVATED TEMPERATURES

Final measurements of deexcitation of nitrogen by water vapor were reported at the 100th Meeting of the Acoustical Society of America in the fall of 1980. The results indicate that the physical process responsible for the deexcitation is not the direct vibration-translation energy transfer, but is a vibration-vibration energy transfer. The results also indicate that ANSI Standard S1.26/ASA 23-1978 predicts an excessive shift of the nitrogen relaxation frequency with humidity. This paper is reproduced in the Appendix.

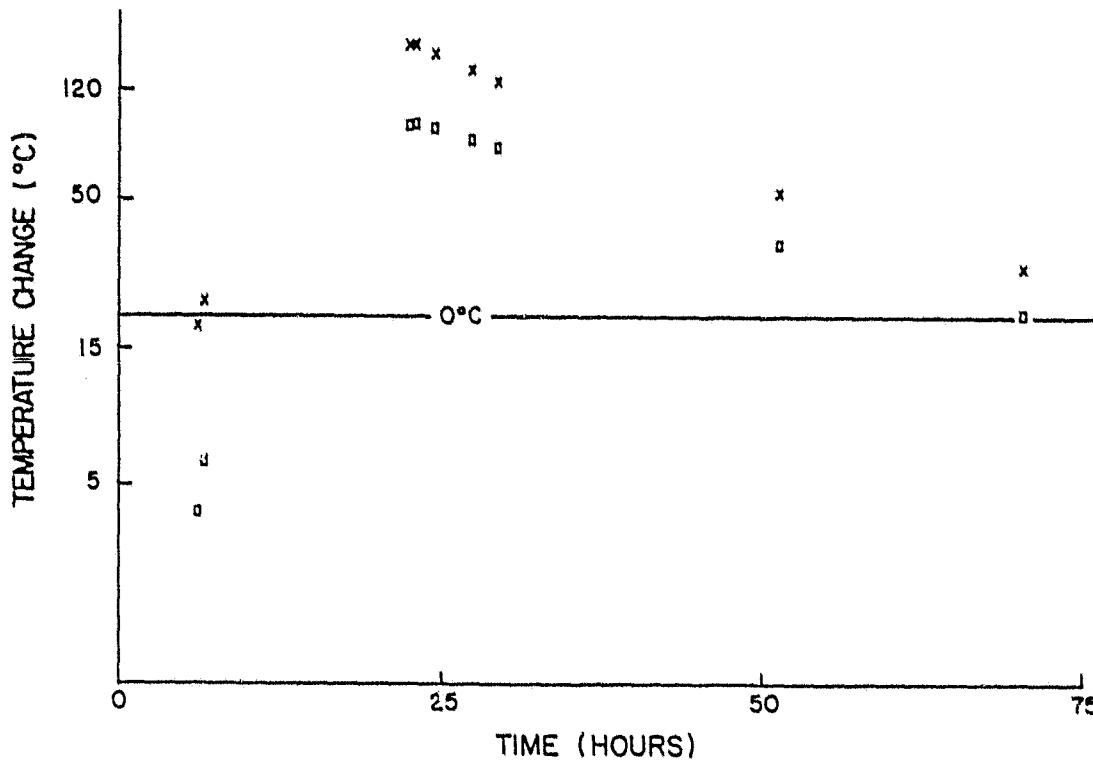


Figure 1. Temperature gradient in one tube section. The large temperature gradient results from liquid  $\text{N}_2$  going in one end and gaseous  $\text{N}_2$  coming out the other end of the tube section.

APPENDIX

SOUND ABSORPTION IN N<sub>2</sub>-H<sub>2</sub>O GAS MIXTURES AT  
ELEVATED TEMPERATURES

By

Allan J. Zuckerwar and Roger W. Meredith

Presented at the 100th Meeting of the Acoustical  
Society of America, fall 1980.

SOUND ABSORPTION IN  $N_2$ - $H_2O$  GAS MIXTURES AT  
ELEVATED TEMPERATURES

By

Allan J. Zuckerwar and Roger W. Meredith

The purpose of our measurements is to make a decisive determination of the physical process responsible for the deexcitation of nitrogen by water vapor, and to compare the measured temperature dependence of the sound absorption with that of the new ANSI standard, "America National Standard Method for the Calculation of the Absorption of Sound by the Atmosphere" (S1.26/ASA 23-1978).

The first slide shows the results of sound absorption measurements in a typical mixture of nitrogen and water vapor at three different temperatures. The water vapor content for this particular composition is 3500 parts per million. The sound absorption  $\mu$ , in nepers/wavelength, is plotted against frequency/pressure ( $f/P$ ) ratio. The data define a pronounced peak - the vibrational relaxation peak of nitrogen - at each temperature. The value of  $f/P$  at the crest of the peak is called the "relaxation  $f/P$ " or " $(f/P)_{max}$ " and lies at about 60 Hz/atm for this mixture.

The data appear in a more or less uniform band about a broad curve, owing to the random nature of the background damping. With increasing temperature the accuracy of the measurement improves considerably as the peak soars above the background. The solid lines represent the best fit to the Debye relaxation curve,  $(f/P)_{max}$  being the only adjustable parameter. The peak height was computed with the aid of the Planck-Einstein formula. Eight such sets of data were taken at humidities ranging from 10 ppm to a maximum of 3 mole %.

Slide 2. Here  $(f/P)_{max}$  is plotted against humidity for 21 of the 24 measured relaxation peaks. The data for the lowest value of humidity fall beyond the range of the graph and are not shown. At low humidities all the data lie on the same straight line, having a slope of 184 Hz/atm·mole %, which is independent of temperature. This agrees well with Griffin's room-temperature slope of 200 Hz/atm·mole %, reported at the Cambridge meeting last year (ref. 1). At high humidities the data deviate from the linear

fit. At 298° K the deviation falls within the experimental error. At the higher temperatures the deviation lies well beyond the error and is considered a real physical effect.

Slide 3. On this slide the relationship between relaxation frequency, referred to 1 atm, and humidity is compared with past results. At low humidities our slope shows good agreement with that obtained by Evans (ref. 2). The data of Chang, Shields, and Bass (CSB) (ref. 3), taken at much higher humidities (starting at 4 mole %), yield the somewhat greater slope of 260 Hz/atm·mole %. The problem is to reconcile the existence of two different slopes at low and high humidities. Fortunately, theory enables us to do this.

Slide 4. The nitrogen-water vapor system is an example of a two-component system, where both components are excitable. Deexcitation of the vibrational degrees of freedom takes place by means of five reactions. The reaction rate  $k_{10}$  for the deexcitation of nitrogen by itself is extremely slow and will be neglected. The second reaction rate  $k_{20}$  represents the deexcitation of nitrogen by water through direct vibrational-translational transfer. Traditionally this reaction has been assumed to be dominant and leads to a strictly linear relationship between  $(f/P)_{\text{max}}$  and humidity, that is, to a single slope. In the model that we propose here  $k_{20}$  is considered small, and the deexcitation process takes place through the last three reactions. Rate  $k_{30}$  represents vibrational-vibrational transfer between the nitrogen and water molecules,  $k_{40}$  the deexcitation of water by itself, and  $k_{50}$  the deexcitation of water by nitrogen.

Slide 5. The Tuesday-Boudart analysis yields the following expression for the slope of the  $2\pi(f/P)_{\text{max}}$  vs.  $h$  relationship in terms of the reaction rate constants. It should be noted that the matrix formulation by Bauer for this particular system yields identical results, but the Tuesday-Boudart analysis is chosen because it lends itself more readily to physical interpretation. The reaction rates  $k_{20}$  and  $k_{10}$  are neglected. Now consider the remaining fraction. At low humidities only the leading terms in the numerator and denominator are important, and these determine the low-humidity slope  $S_1$ . At high humidities the latter terms in the numerator and denominator become dominant; and when only these are retained, we obtain a different slope—the high-humidity slope  $S_2$ . Thus, the theory leads to one value of slope at low humidities and another value of

slope at high humidities. The situation is quite different in the oxygen-water vapor system, where the reaction  $k_{03}$  is so large that the second term in the denominator never really becomes dominant for values of humidity normally encountered.

Slide 6. The function  $S(h)$  is plotted against humidity on a logarithmic scale. The circles are Griffin's data points at room temperature. The triangles are the data of the CSB group (ref. 3). The solid line is the best fit of the Tuesday-Boudart formula to both sets of data with  $k_{40}$  as the only adjustable parameter. Thus the V-V model not only accounts for the existence of two slopes, but also fits both sets of data. There are two possible objections to the V-V interpretation. First, the rate constant  $k_{40}$  for the deexcitation of water by itself is smaller than the values obtained from past experiments. The dash lines are similar plots using other values of  $k_{40}$  derived from the literature. Actually, a value of  $k_{40}$  as high as  $5 \times 10^7$  is consistent with the data. Secondly, it might be argued that a single straight line, with a slope somewhat less than  $1.5 \times 10^5$ , would fall within the error bounds of the bulk of the data. This is true for the room-temperature data and is our primary motivation for obtaining the more accurate data at elevated temperatures.

Slide 7. Here we see slope versus log humidity for all three temperatures. As before the solid lines are best fits of the Tuesday-Boudart formula. At room temperature the existence of two slopes is barely noticeable and concealed within the experimental error. The situation changes at higher temperatures, where the change of slope at high humidity lies well beyond the experimental error. A triangle represents a CSB point at the closest corresponding temperature. Agreement is quite good.

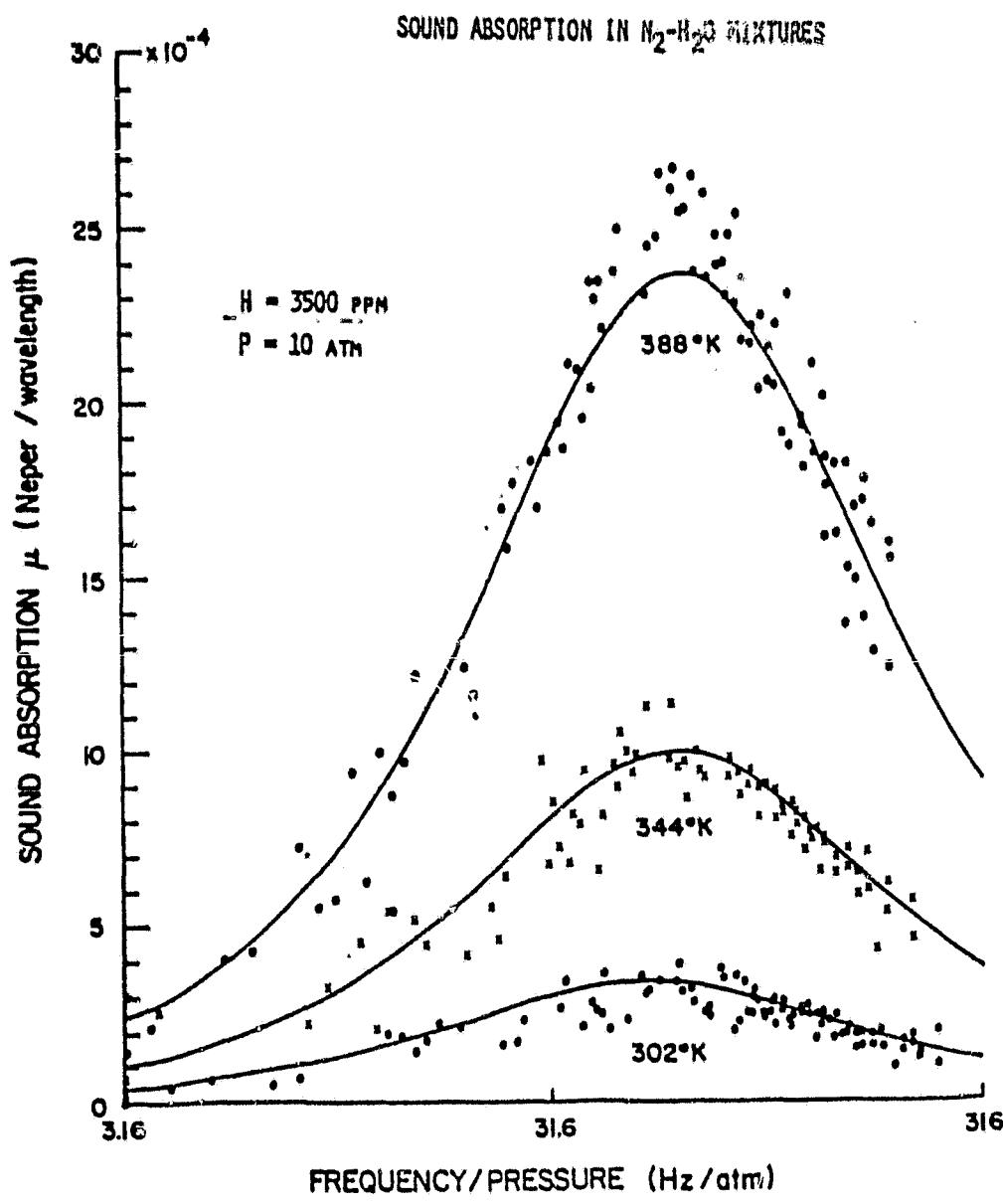
Slide 8. This is a Landau-Teller plot for the V-V process. The solid circles are derived from the low-humidity slope. The rate constant represents a series combination of  $k_{30}$  and  $k_{50}$  and is independent of temperature. The remaining data belong to the high-humidity slope  $k_{30}$ . The solid line is the best fit to our own and past data. The data chosen to determine the line are those points whose error bars intersect the line; these include Henderson's point (ref. 4), three CSB points, Evan's point, and three of our own. Each point is weighted according to how many humidity values were used to establish the slope. The shock tube data

of Huber and Kantrowitz (ref. 5) show too much scatter and are not included. Once we get above room temperature the error assigned to the various data points demonstrates the existence of two slopes beyond any doubt.

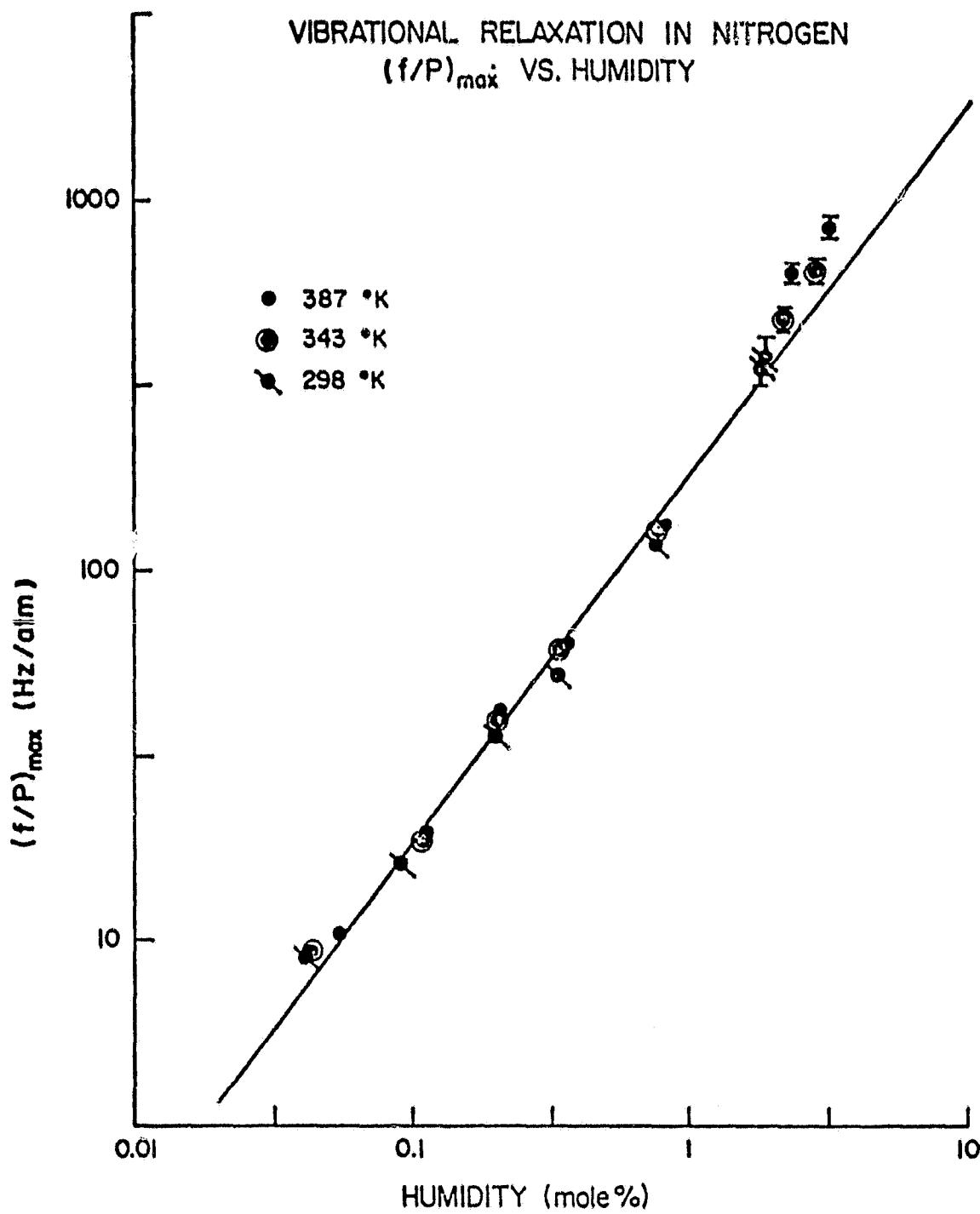
Slide 9. We analyzed our own data and accounted for the 78 percent dilution in air to compare our measured relaxation frequencies with those specified by the new ANSI Standard. The values chosen correspond to the extremes of temperature and humidity specified in the standard. The first thing to notice is that the standard predicts far too great a shift of the nitrogen relaxation frequency with humidity. The standard is in error anywhere from 35 to 75 percent. Secondly, the standard does not account for the change in slope. However, a tenfold increase in humidity produces only a slightly greater than tenfold increase in relaxation frequency, so that the error due to the two-slope effect is not very serious. Finally, a 40° C increase in temperature increases the relaxation frequency by a factor of 8.5 according to the standard but by a factor of 13 according to measurement. For frequencies below 2000 Hz, where sound absorption in nitrogen becomes the dominant process in the Earth's atmosphere, the new ANSI Standard, while more accurate than anything available previously, could still lead to a substantial measurement error.

#### REFERENCES

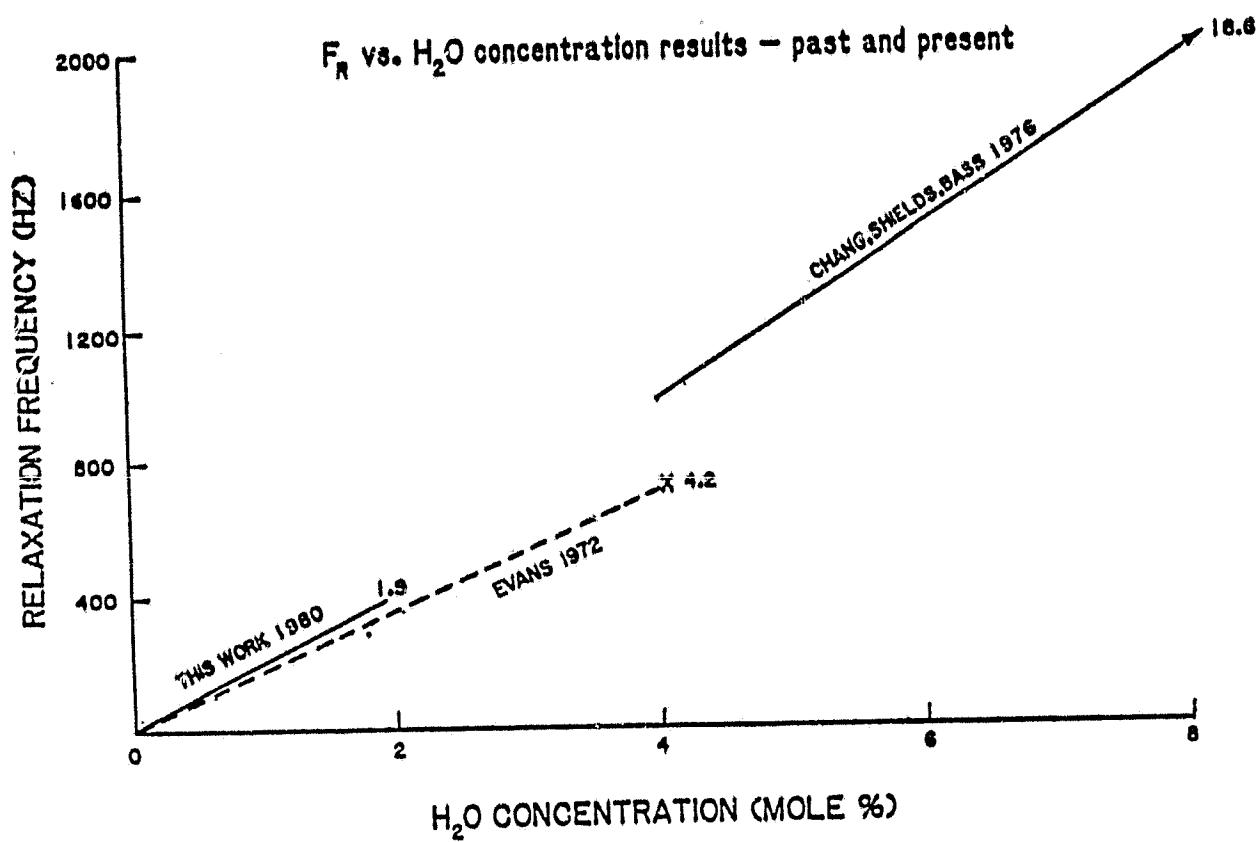
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4. M.C. Henderson et al., J. Acoust. Soc. Am. 45, 109-114 (1969).
5. P.W. Huber and A. Kantrowitz, J. Chem. Phys. 15, 275-281 (1947).



Slide 1

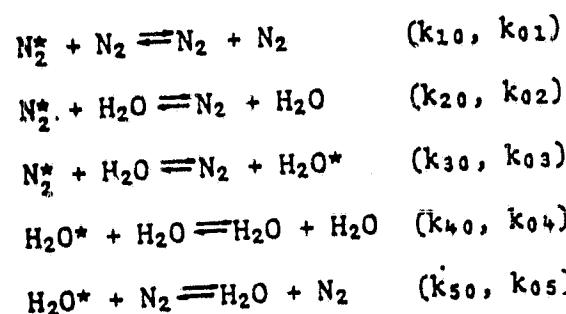


Slide 2



Slide 3

### Reaction Rates



Slide 4

Slope According To Tuesday - Boudart

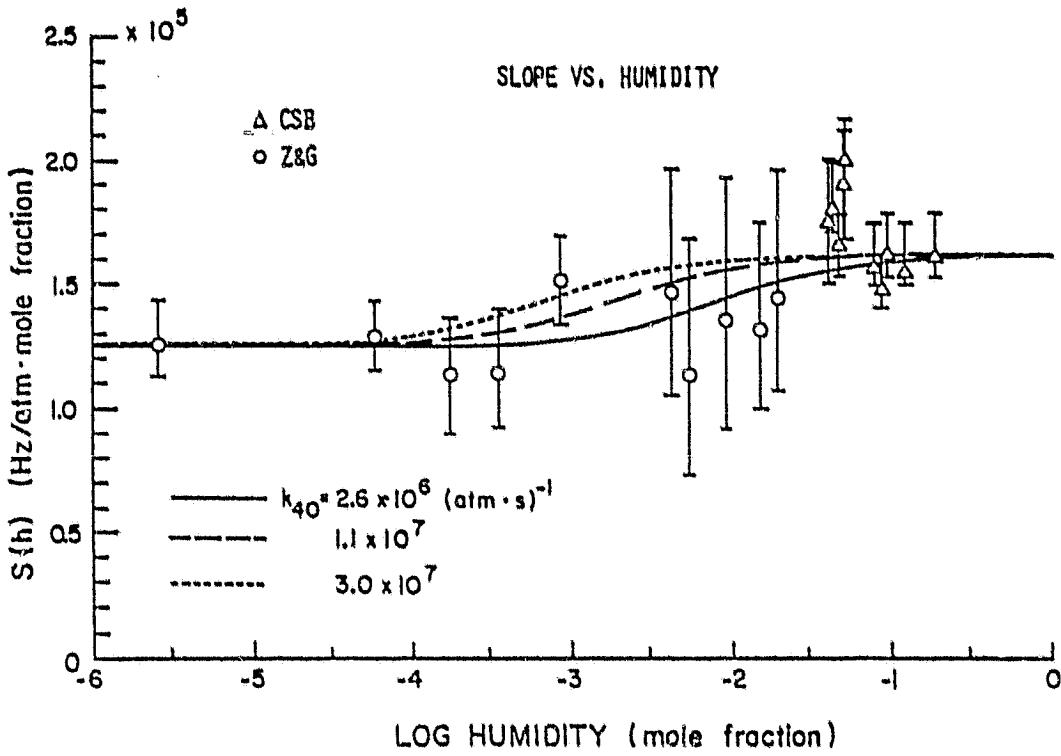
$$S(h) = \frac{[2\pi(f/P)]_{\max} - k_{10}}{h}$$

$$= k_{20} - k_{10} + \frac{k_{30}k_{50} + k_{30}(k_{40} - k_{50})h}{k_{03} + k_{50} + (k_{40} - k_{50} - k_{03})h}$$

$$S(h) + S_1 = k_{20} - k_{10} + \frac{k_{30}k_{50}}{k_{03} + k_{50}} \quad (h \text{ small})$$

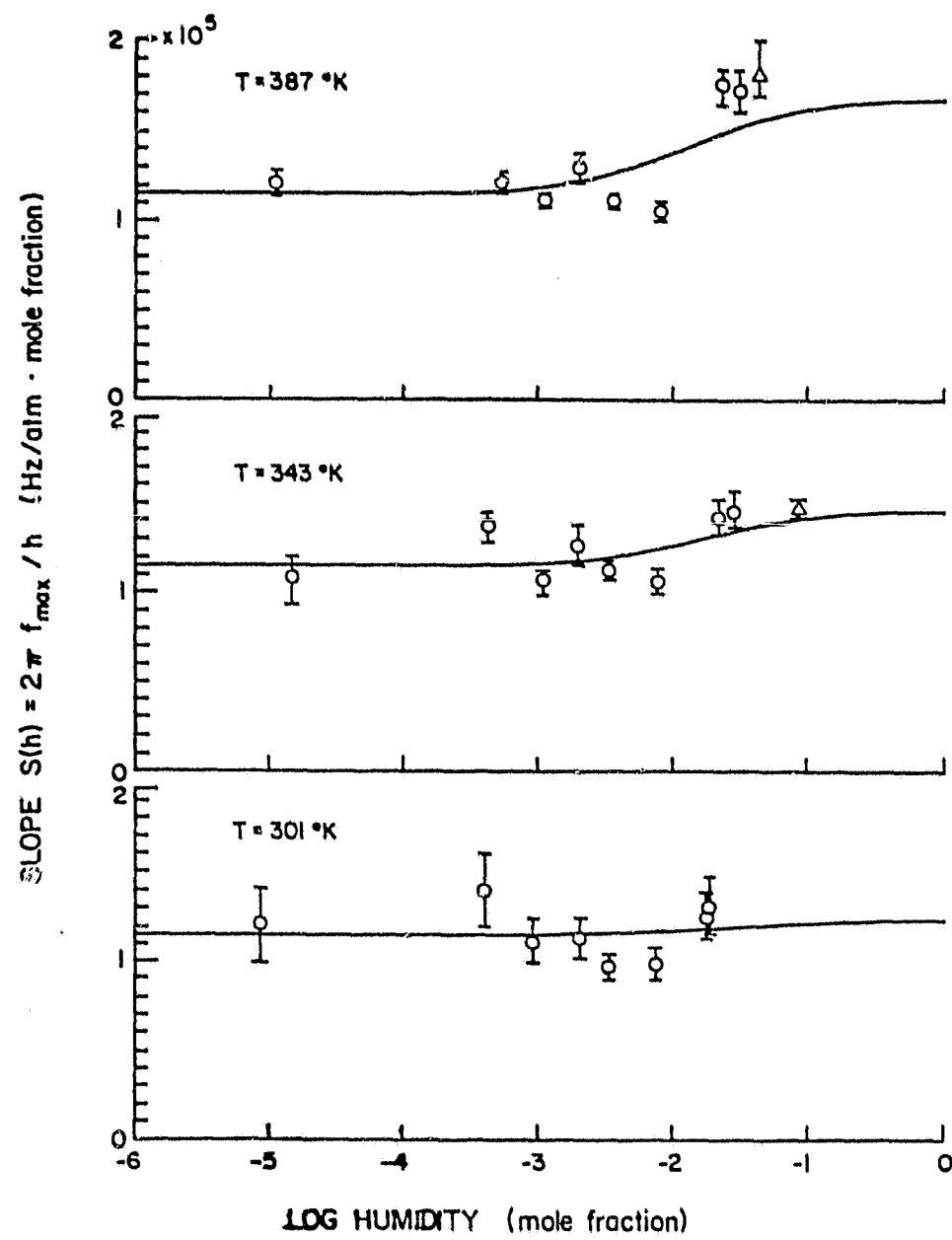
$$S(h) + S_2 = k_{20} - k_{10} + \frac{k_{30}(k_{40} - k_{50})}{k_{40} - k_{50} - k_{03}} \quad (h \text{ large})$$

Slide 5

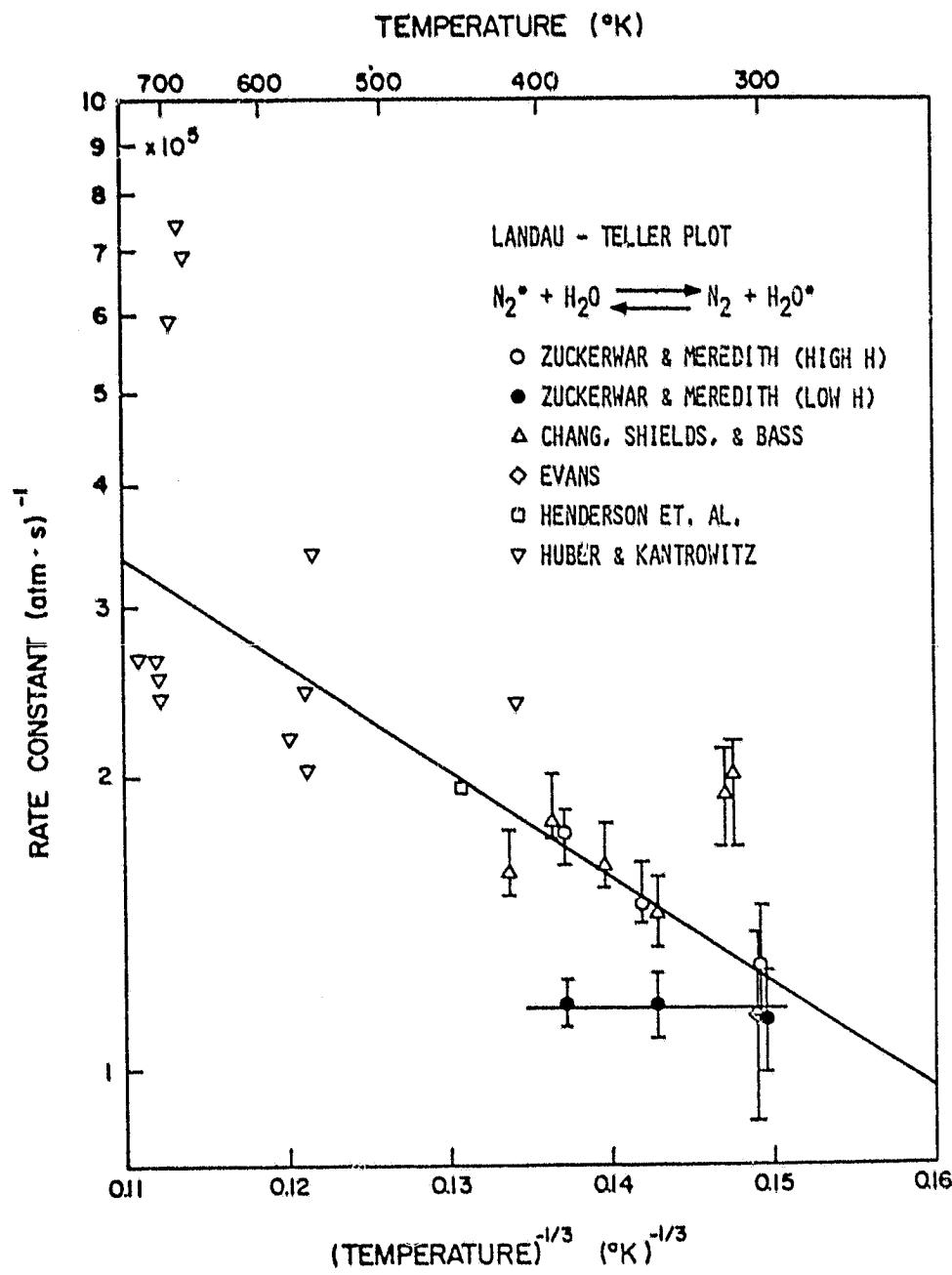


Slide 6

SLOPE VS. HUMIDITY



Slide 7



Slide 8

RELAXATION FREQUENCY OF NITROGEN IN AIR AT 1 ATM

		R.H. = 10%	R.H. = 100%
T=273°K	Z&M ANSI	8.65 Hz 21.11	87.18 Hz 211.05
T=313°K	Z&M ANSI	108.17 <u>179.19</u>	1154.44 <u>1791.90</u>

Slide 9